Square microstrip multi band fractal antenna using EBG structure for wireless applications

Suresh Akkole and Vasudevan N.
Hindustan Institute of Technology and Science, Chennai, India

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Abstract

Purpose – Application of electromagnetic band gap (EBG) i.e. electromagnetic band gap technique and its use in the design of microstrip antenna and MIC i.e. microwave integrated circuits is becoming more attractive. This paper aims to propose a new type of EBG fractal square patch microstrip multi band fractal antenna structures that are designed and developed. Their performance parameters with and without EBG structures are investigated and minutely compared with respect to the resonance frequency, return loss, a gain of the antenna and voltage standing wave ratio.

Design/methodology/approach – The fractal antenna geometries are designed from the fundamental square patch and then EBG structures are introduced. The antenna geometry is optimized using IE3D simulation tool and fabricated on low cost glass epoxy FR4, with 1.6 mm height and dielectric materials constant of 4.4. The prototype is examined by means of the vector network analyzer and antenna patterns are tested on the anechoic chamber.

Findings – Combining the square fractal patch antenna with an application of EBG techniques, the gain of microstrip antenna has been risen up and attained good return loss as compared to the antennas without EBG structures. The designs exhibit multi-frequency band characteristics extending in between 1.70 and 7.40 GHz. Also, a decrease in antenna size of 34.84 and 59.02 per cent for the first and second iteration, respectively, is achieved for the antenna second and third without EBG. The experimental results agree with that of simulated values. The presented microstrip antenna finds uses in industrial, scientific and medical (ISM) band, Wi-Fi and C band. This antenna can also be used for satellite and radio detection and range devices for communication purposes.

Originality/value – A new type of EBG fractal square patch microstrip antenna structures are designed, developed and compared with and without EBG. Because of the application of EBG techniques, the gain of microstrip antenna has been risen up and attained good return loss as compared to the antennas without EBG structures. The designs exhibit multi-frequency band characteristics extending in between 1.70 and 7.40 GHz, which are useful for Wi-Fi, ISM and C band wireless communication.

Keywords Microstrip antenna, Fractal, Electromagnetic band gap, Multiband, Surface waves

Paper type Research paper

1. Introduction

In the present scenario, there has been an enormous consistently developing demand in consumer electronics market, for planar antennas especially microstrip patch antenna design, model invention and production for customers and military security purposes because of their attractive features (small size, thin, conformal and capable to operate in multi-band) (James and Hall, 1989). Traditional antennas ordinarily function at only one frequency band, where different antennas structures are required for separate communication applications. Therefore, there exists the requirement of copious space for the

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design of different antennas. Hence, to solve this difficulty, multi-frequency microstrip patch antennas can be replaced by a single antenna to operate at various separate frequency bands. As stated earlier, microstrip antennas are suitable for dual-band and/or multi-band wireless device applications (Garg and Bartia, 2001). A fractal antenna is a good candidate for getting multiband and for size reduction (Mandelbrot, 1983). The fractal term stands for irregular or broken shapes. The two basic fractal properties are self-affine and self-similar. In self-affine, the fractal shape is reduced in both directions (x and y) by the variable amount and in self-similar fractal whole structure is reduced in both directions by the equal amount. Self-affine property of fractal has been used in the present work.

The electromagnetic energy radiated from the antenna radiating element in various directions and excitation of surface waves that are formed in the dielectric material sheet limits its efficiency (Saberi Dalenjan *et al.*, 2016). So as to diminish surface waves and to enhance the antenna performance characteristics electromagnetic band gap (EBG) structure is used on the microstrip antenna. Because of possession of its periodic lattices i.e. periodical metal fixes on the top of the material, EBG structure can give good and variable control over the electromagnetic wave transmission within a specified frequency band (Qian *et al.*, 1999). The EBG slots exhibit multiband, increase antenna bandwidth (BW) and improve input return loss S_{11} of microstrip patch by reducing the redundant surface waves as depicted in Figure 1 (Anandakumar and Umamaheswari, 2017).

1.1 Related work

The lower antenna gain and poor efficiency of radiation are the basic problems associated with multi-frequency microstrip antennas over its operating frequency bands because of surface waves. In the past, it has been presented that EBG structures can effectively decrease the return loss parameter of the patch and increase the gain by reducing undesired surface waves. In the past, several works have been reported to overcome the above stated microstrip antenna limitations. The gain of microstrip patch antenna having probe fed technique has been enhanced by elliptical EBG structure is reported in (Zoubiri *et al.*, 2016). In other work Sierpinski carpet antenna designed and applied uniplanar EBG slots for fifth-generation applications (Karthikeya *et al.*, 2017). The stacked mushroom-structured EBG slots and its design methodologies are also have been discussed and presented (Moharam Hassan and Kishk, 2017).

Also, a Sierpinski carpet microstrip fractal patch antenna by placing EBG slots in the ground structure is being developed to improve BW and shrink the size of the antenna for x band radio communication applications (Dhakad *et al.*, 2017). The EBG structure of mushroom shape was used to decrease mutual coupling at the frequency of 5.6 GHz but the gain has been lowered because of the interaction of patch antenna and EBG arrays

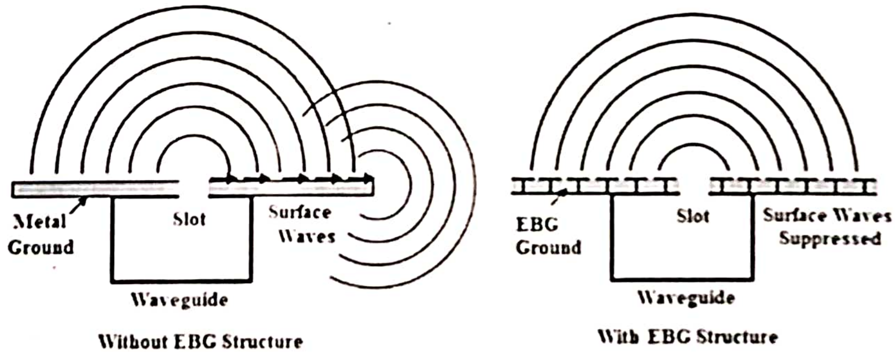


Figure 1.
The suppression of unwanted surface waves by EBG structure

(Naderi *et al.*, 2018). In another work, the effect of implementing EBG cell structures on the elements of reflection coefficients in the microstrip patch phased array antenna during the scanning of the beam is studied for mono pulse tracking radar applications (Jam and Simruni, 2018). The study of an adaptable fractal antenna with EBG and wearable coplanar wavegide antenna for 20-40 GHz frequency range was also presented for millimeter waves where backward radiation is decreased by 15 dB (Lin *et al.*, 2018). An ultra-wideband microstrip patch antenna design with the use of fractal EBG and two via edge located-EBG slots are reported in Trimukhe and Hogade (2019) to obtain ternary band-notched characteristics and finds applications in downlink satellite telecommunication, wireless local area network and worldwide interoperability for microwave access (WiMAX) frequency bands. The study of rectangular microstrip patch antenna with EBG slots is carried out to monitor the radiation plot of the antenna is also reported for use in wireless and satellite applications (Abdulhameed *et al.*, 2019).

This proposed work examines the performance characteristics of a square slotted fractal patch antenna incorporated with the EBG structure of planar square-shaped slots. It is seen that the presented microstrip patch antenna having EBG slots enhances the antenna gain and return loss than a non-EBG structure. The presented design shows antenna operating at multi resonant frequency bands with wider BW and peak gain using fractal geometry. The simulated results obtained show that the designed square microstrip fractal antenna with EBG resonates at multiband frequencies with better impedance BW, increased return loss and improved antenna gain. Therefore, the enhancement of gain, the achievement of multi-frequency and low voltage standing wave ratio (VSWR) of square microstrip antenna is presented by EBG. Section 2 describes the design part of the proposed antenna and its function. Results and discussion and validation of experimental results are reported in Section 3. At the end conclusions of the proposed investigation work are included in Section 4.

2. The design of microstrip antenna

2.1 Basic antenna geometry (iteration 0 of antenna 1)

The use of basic antenna geometry is made here and applied to a square-shaped microstrip patch antenna by using a coaxial cable feed technique and its measurements determine the operating resonance frequency (f_r). The design of basic square antenna structure is made by the use of equations (1)-(5) (Werner and Ganguly, 2003; Chatterjee *et al.*, 2019; Kohli *et al.*, 2013; Dalmiya and Sharma, 2016; Sureshkumar *et al.*, 2018; Abirami and Sundarsingh, 2017; Saberi Dalenjan *et al.*, 2016; Jagadeesha *et al.*, 2013; Sureshkumar *et al.*, 2018; Ismahayati *et al.*, 2011; Tang and Wahid, 2002; Pourahmadazar *et al.*, 2010; Krauss *et al.*, 2010; Balaji *et al.*, 2016; Khanna *et al.*, 2015; Hazan *et al.*, 2016; Behera, 2017), and the designed antenna has size of 29 mm^2:

$$W = \left(\frac{c}{2f_r}\right)\left(\frac{\sqrt{2}}{\sqrt{(\varepsilon_r + 1)}}\right) \tag{1}$$

$$\varepsilon_{reff} = (\varepsilon_r + 1)/2 + \frac{\varepsilon_r - 1}{2}\sqrt{1 + (12h/w)} \tag{2}$$

$$L = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\Delta L = L + 2\Delta L \quad (4)$$

$$\Delta L = (0.412h)\left[\frac{(\varepsilon_{reff} + 0.3)\left(\left(\frac{W}{h}\right) + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\left(\frac{W}{h}\right) + 0.8\right)}\right] \quad (5)$$

where:

ε_r = constant of dielectric substrate;
h = height of dielectric material;
ε_{reff} = effective dielectric constant;
ΔL = microstrip patch antenna length extension;
L = length of the patch antenna;
W = width of microstrip patch antenna;
c = speed of light; and
fr = antenna resonant frequency.

All the patch antenna designed geometries reported in this research are made use of FR-4 glass epoxy as a substrate having ε_r = 4.4 (dielectric constant), with 0.02 loss tangent and height of substrate = 1.6 mm.

Figures 2(a) and 2(b) reveal the geometry of the designed microstrip antenna 1, with iteration 0 of size 29 × 29 mm with its radiation pattern. The antenna simulation IE3D tool is used for the optimization of results by performing more number of iterations to obtain an enhanced gain, improved impedance BW and multiband frequency of operation. The overall microstrip antenna ground plane area ($Lg_0 \times Wg_0$) is kept at 39 × 39 mm. Figures 2(c) and 2(d) show the proposed square antenna with EBG structure of square shape of 6.5 mm^2 sizes with 1 mm gap between them and its three-dimensional radiation pattern. The height of EBG structure is kept at 1.6 mm. This antenna structure is small in size and has a better ability to give flexible shape and peak efficiency because of antenna surfaces. Also, the three-dimensional radiation plot shows good omni-directional characteristics.

2.2 Antenna 2, with iteration 1

Figures 3(a) and 3(b) shows the geometry of the designed square patch antenna 2 by iteration 1 and its three-dimensional radiation pattern. The structure 29 × 29 mm of Figure 2(a) is reduced to 1/3 because of this 9.66 × 7.25 mm sized 12 rectangular slots of are created. Out of 12 rectangular slots only 6 slots are preserved and the remaining 6 slots are deleted to obtain fractal antenna and further out of 6 slots central two slots along the direction of the x-axis, the length is modified to 9.66/3 = 3.22 mm to get microstrip fractal antenna of self-affine type.

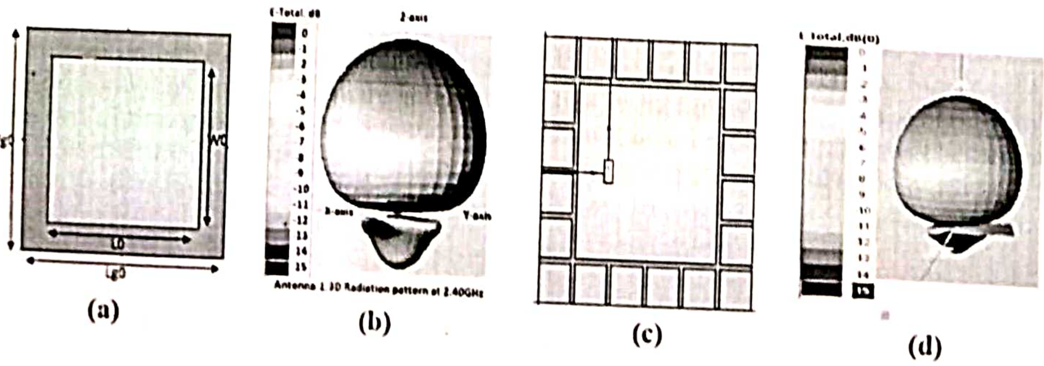


Figure 2.
a) Basic patch antenna 1 geometry without EBG; b) its radiation plot at frequency 2.4 GHz; c) basic patch antenna 1 geometry with EBG; d) its radiation plot at 2.4 GHz frequency with EBG

The microstrip patch ground plane area ($Lg_1 \times Wg_1$) is here also kept at 39 × 39 mm. Figures 3(c) and 3(d) depict the configuration of the planned square antenna 2 and its three-dimensional radiation plot with EBG square shape structure of 6.5 mm^2 sizes with a 1 mm gap between them. The height of EBG structure is kept at 1.6 mm apart. The various fractal design values are tabulated as shown in Table I. Antenna simulation IE3D tool is used for the optimization of results by performing more number of iterations to obtain an enhanced gain, improved impedance BW and multiband frequency. The practical measurements of antennas have been carried out and recorded. It may be noted that from the first iteration the antenna 2 area was reduced by 34.84 per cent in comparison with antenna 1without EBG. The simulated three-dimensional radiation plots with EBG at frequency 6.74 GHz indicate that antenna 2 also shows a radiation pattern of omni-directional and enhanced gain.

2.3 Antenna 3, iteration 2

Figures 4(a) and 4(b) depicts the designed geometry of antenna 3 for iteration 2 and its three-dimensional radiation pattern. From the geometry of Figure 3(a), the 4 slots of the area of 9.66 × 3.22 mm are condensed to 1/3 because of these 12 rectangular structures of area 3.22 × 2.41 mm in all 4 slots are created. Out of 12 rectangles, 6 rectangles are deleted and

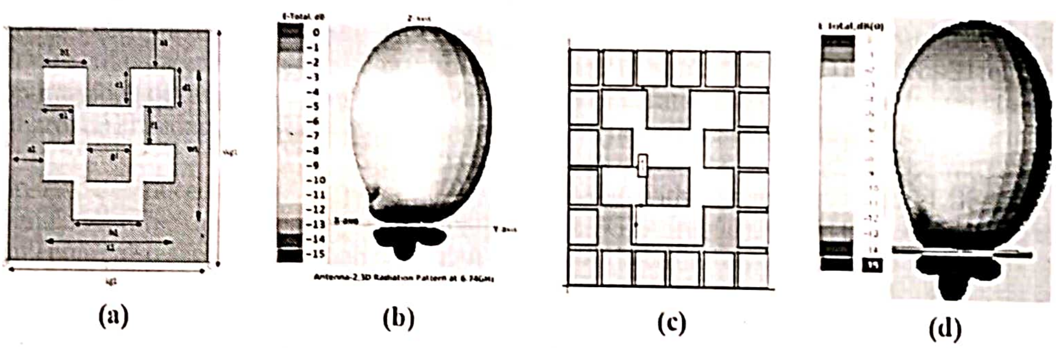


Figure 3. (a) Geometry of patch antenna 2 without EBG; b) antenna 2 radiation plot at frequency 6.45 GHz without EBG; c) geometry of antenna 2 with EBG; d) antenna 2 radiation patterns at 6.74 GHz with EBG

Table I. Various parameters list of antenna 2 geometry

Parameter	a_1	b_1	c_1	d_1	e_1	f_1	g_1	h_1
Measurement (mm)	5.001	9.667	7.250	7.250	6.441	7.251	9.661	16.100

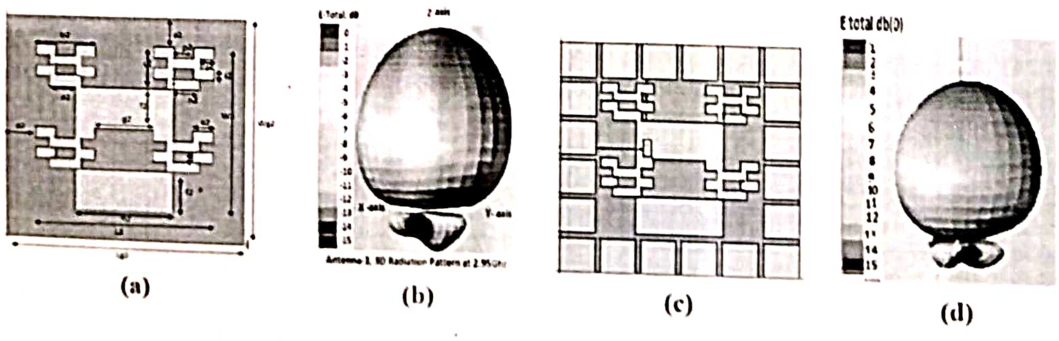


Figure 4. (a) Geometry of antenna 3 without EBG; (b) antenna radiation pattern at frequency 2.95 GHz without EBG; (c) antenna 3 geometry; (d) radiation plots at frequency 2.95 GHz with EBG

the other 6 are retained in all 4 slots. Further out of 6 rectangular two center patch rectangular structures lengths are minutely modified along of x-axis direction by 3.22/3 = 1.07 mm apart to get fractal antenna of self-affine type as depicted in Figure 4(a). The overall microstrip ground plate area ($L_{g2} \times W_{g2}$) is kept at 39 × 39 mm. Figures 4(c) and 4(d) shows the EBG structure of a square of 6.5 mm size with a 1 mm gap between them and its radiation pattern. The height of the EBG structure here also kept at 1.6 mm only. From iteration 2 it would be clear that the antenna 3 total area shrinks in size by an amount 59.020 per cent in comparison with antenna 1 without EBG. Simulations have been repeated at different feed positions to get better results for the geometry. The various fractal antenna designed parameters are tabulated as shown in Table II. The three-dimensional radiation plot of simulated antenna 3 at 2.95 GHz depicts it has omni-directional radiation pattern and improved gain with EBG structure.

3. Results and discussion

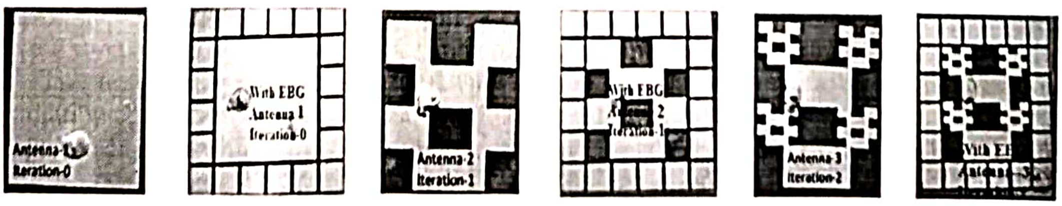
All the designed antenna structures presented in Section 2 have been fabricated and examined without and with EBG slots and are depicted in Figures 5(a)-5(f).

The demonstrated antennas have been examined on the vector network analyzer. The measured and simulated results found without and with EBG structures are tabulated in Tables III. Figure 6(a) illustrates the comparative study and analysis of simulated, having EBG and not having EBG structure of basic antenna 1 for the return loss S_{11}. From the patterns, it is seen that the readings of the return loss of both simulated and practical, with and without EBG are relatively very close to each other. The antenna radiation plots testing and measurements have been done in an anechoic compartment and are shown in Figures 6(b) and 6(c) for without EBG and with EBG structure for antenna 1. The experimental values obtained are quite close to the simulated readings and the cross polarization parameter readings are lower than −20dB.

The antenna 1 radiation pattern shows good co-polarization and cross polarization radiation characteristics in contrast with antenna 1 without EBG slots. The radiations plots reported here also illustrate the omni-directional characteristics and finds applications in

Table II. Various parameters list of antenna 3 design

Parameter	b_2	c_2	d_2	e_2	f_2	g_2	h_2	i_2	j_2	k_2
Measurement (mm)	9.660	7.250	7.250	6.440	7.250	9.660	16.100	9.660	9.660	16.100



(a) (b) (c) (d) (e) (f)

Figure 5. Fabricated microstrip patch antennas: (a) and (b) basic patch antenna 1 without EBG and with EBG; (c) and (d) antenna 2 without EBG and with EBG; (e) and (f) antenna 3 without EBG and with EBG, respectively

Table III. Comparison table of different iterations with and without EBG

Antenna types	Resonance frequency (GHz) Simulated	Resonance frequency (GHz) Measured	Return loss (S_{11}) (dB) Simulated	Return loss (S_{11}) (dB) Measured	VSWR Simulated	VSWR Measured	Antenna gain (dB) Simulated	Antenna gain (dB) Measured
Antenna 1 iteration 0 without EBG	2.41	2.40	−17.35	−11.37	1.30	1.74	2.12	2.16
	4.76	4.75	−18.08	−13.40	1.29	1.54	1.17	−9.10
	5.46	5.50	−25.12	−10.99	1.13	1.77	−0.02	−16.0
	7.08	7.18	−11.33	−28.42	1.84	1.06	4.28	4.65
Antenna 1 iteration 0 with EBG	2.400	2.386	−19.25	−11.50	1.21	1.70	2.47	2.60
	4.720	4.786.	−15.25	−20.26	1.33	1.23	3.22	−9.05
	5.150	5.480	−19.09	−13.59	1.24	1.52	1.02	3.89
	–	7.026	–	−15.35	–	1.42	–	4.15
Antenna 2 iteration 1 without EBG	2.01	2.01	−13.08	−12.49	1.96	1.64	−6.22	−20.0
	2.93	2.97	−15.76	−21.03	1.86	1.19	0.15	−22.0
	4.70	4.78	−13.62	−17.28	1.75	1.32	1.48	−1.70
	7.13	7.40	−11.08	−26.96	1.73	1.10	3.60	5.40
Antenna 2 iteration 1 with EBG	2.020	2.013	−10.80	−22.06	2.08	1.17	−4.3	−6.94
	2.932	2.973	−14.93	−10.20	1.46	1.89	−1.64	3.43
	4.704	4.733	−11.22	−21.95	1.77	1.98	1.27	−6.4
	6.691	7.293	25.23	−24.83	1.11	1.11	4.8	5.76
Antenna 3 iteration 2 without EBG	1.78	1.82	−11.95	−10.62	1.70	1.97	−6.12	−17.0
	1.99	1.99	−12.63	−13.12	1.60	1.68	−9.23	−10.0
	2.91	2.95	−14.26	−24.10	1.57	1.25	0.23	2.19
	4.32	4.40	−22.47	−15.62	1.18	1.42	−3.24	−2.02
	8.67	8.80	−29.03	−22.7	1.07	1.2	3.46	3.8
Antenna 3 iteration 2 with EBG	1.98	1.96	−10.59	−11.57	2	2.18	−1.41	−7.9
	–	2.92	–	−11.91	–	1.69	–	2.25
	4.32	4.36	−17.29	−24.15	1.41	1.25	−2.97	−8.92
	8.57	8.68	−20.56	−17.53	1.20	1.31	1.89	2.10

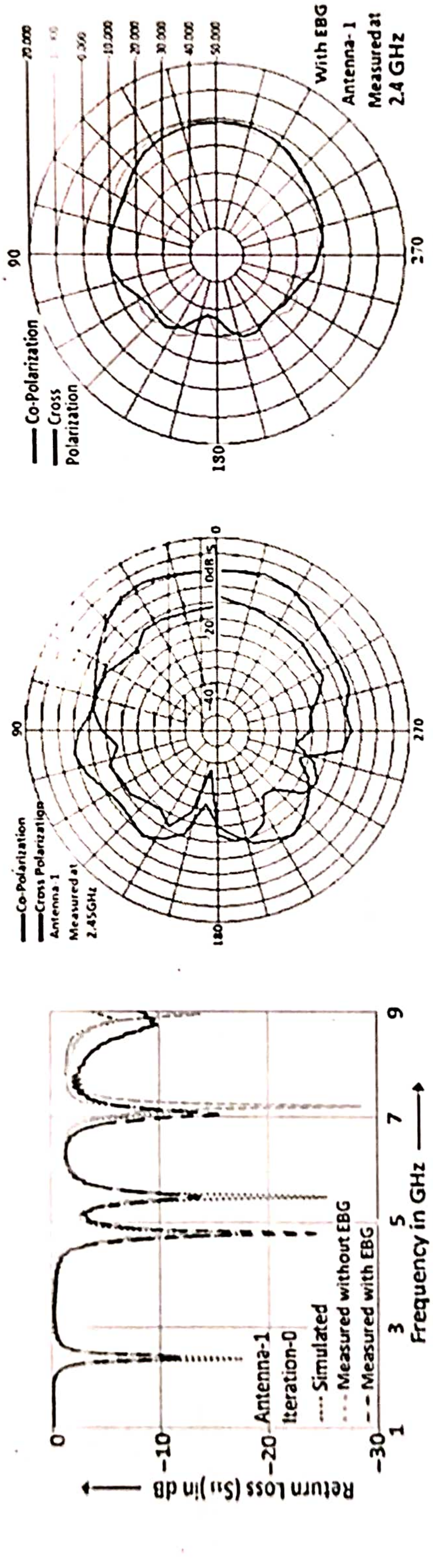


Figure 6.
Input characteristics of antenna geometry 1: (a) return loss vs frequency; (b) radiation plot without EBG; (c) radiation plot with EBG

wireless communications such as Wi-Fi, WiMAX, and industrial, scientific and medical (ISM) frequency bands.

The observed and simulated antenna gains are 2.11 and 2.12 dB at 2.40 GHz, and 4.65 and 4.28 dB at 7.18 and 7.08 GHz frequency, respectively.

The basic antenna 1 works at multi-frequency band with peak return loss at antenna resonance frequencies 2.4, 4.75, 5.50 and 7.08 GHz. A peak frequency BW of 107 MHz at 7.18 GHz is reported with EBG. The simulated, antenna and radiation efficiency obtained with and without EBG 41.57 and 43.59 per cent and 41.30 and 43.08 per cent at 2.40 GHz frequency, respectively.

The antenna 2 with iteration1 functions at four multiband frequencies i.e. on 2.01, 2.97, 4.78 and 7.40 GHz, respectively. As depicted in Figure 7(a), the simulated and experimental results indicate that antenna 2 has better return loss and low VSWR. The measured and simulation gain of 9.4 and 3.60 dB are found at about 7 GHz resonance frequency. The simulated antenna and radiation efficiency without EBG found are 45.6 and 54.5 per cent at 7.44 GHz frequency and with EBG 39.93 and 30.88 per cent at 6.69 and 7 GHz, respectively. Figure 7(a) depicts the comparative study and analysis of measured and simulated, having EBG and without having EBG slots of basic antenna 2 for the return loss S_{11}, respectively. The antenna 2 with EBG radiation pattern shows good co-polarization and cross polarization results in comparison with antenna 2 without EBG. The plots of antenna radiation indicate omni-directional characteristic at 6.75 GHz as shown in Figures 7(b) and 7(c).

The antenna 3 also works at multi-frequency bands with measured peak return losses of −10.62, −13.12, −24.10, −15.62 and −29.03 dB at antenna resonance frequencies 1.82, 1.99, 2.95, 4.40 and 8.80 GHz, respectively, with peak BW of 46 MHz is obtained at 2.95 GHz and gain of 3.80 dB at 8.80 GHz achieved. Further, these resonance frequencies are well matched for the ISM frequency band, Wi-Fi and C frequency band uses. Figure 8(a) indicates antenna 3 relative study and investigation of its return loss S_{11} parameter. The antenna two-dimensional radiation plot without and with EBG is revealed in Figures 8(b) and 8(c) depicts a steady radiation pattern at frequency 2.95 GHz. The simulated antenna and radiation efficiency without EBG results in 38.13 per cent at 8.61 GHz frequency and with EBG 33.34 per cent at 8.55 GHz, respectively. In summary, there is a rise in return loss, gain and VSWR with an application of EBG slots in a comparison with an antenna without EBG slots.

4. Conclusions

Square patch microstrip multi band fractal antenna with and without EBG structures has been presented. The presented antenna geometry indicates better results in comparison with the general squarer patch antenna with EBG in terms of radiation efficiency, return loss, gain and VSWR. The antenna design along with investigation done in this proposed research work with respect to iterations 0, 1 and 2, it is clear from that the square patch fractal antenna with EBG structure offers better results over conventional square fractal patch without EBG structure. The gain of the antenna is enhanced with the incorporation of EBG structure on antenna surface and lowers the back lobe antenna radiations. The multiband operating frequencies achieved with optimal results having EBG structure are 2.3957 GHz with BW of 75.511 MHz and 5.48 GHz with BW of 178.797 MHz having gain of 3.43 and 3.89 dB, respectively. These multiband resonant frequencies are useful for applications in S band. The frequency component 7.293 GHz having a peak gain of 5.76 dB is achieved with EBG structure for iteration 1. The presented results also show an overall reduction antenna size. With these results, the presented antenna geometry is useful for radar and ultra wide band communication purposes.

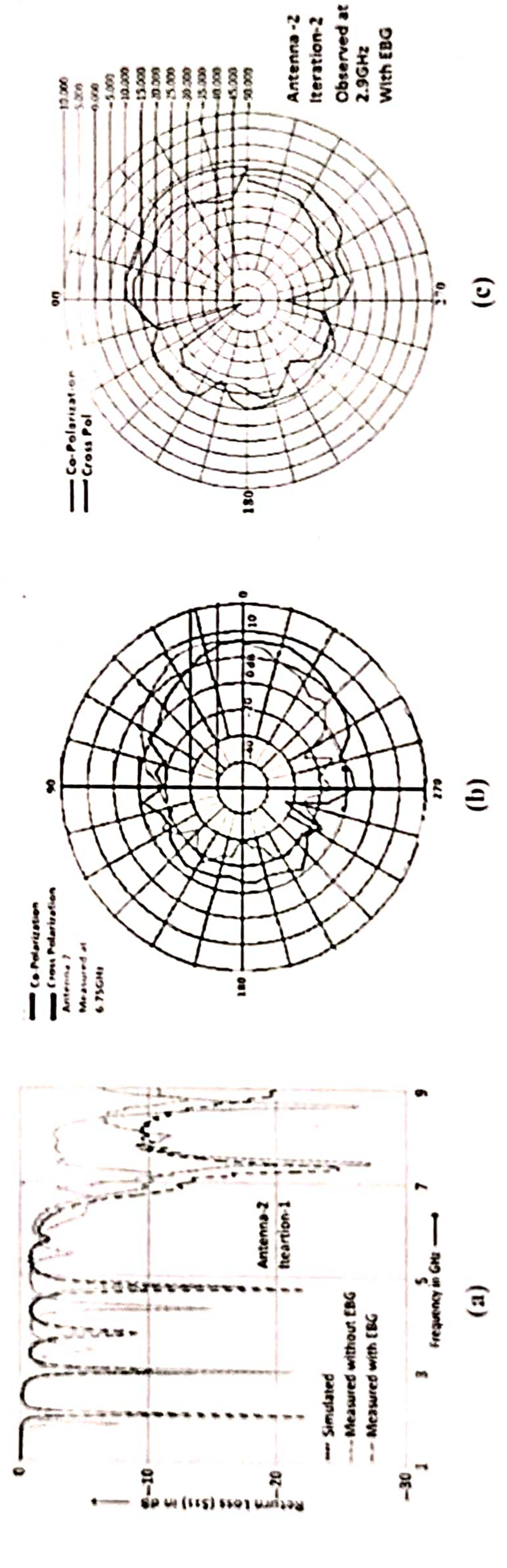


Figure 7.
Input characteristics of antenna geometry 2: (a) return loss vs frequency; (b) radiation plot without EBG; (c) radiation pattern with EBG

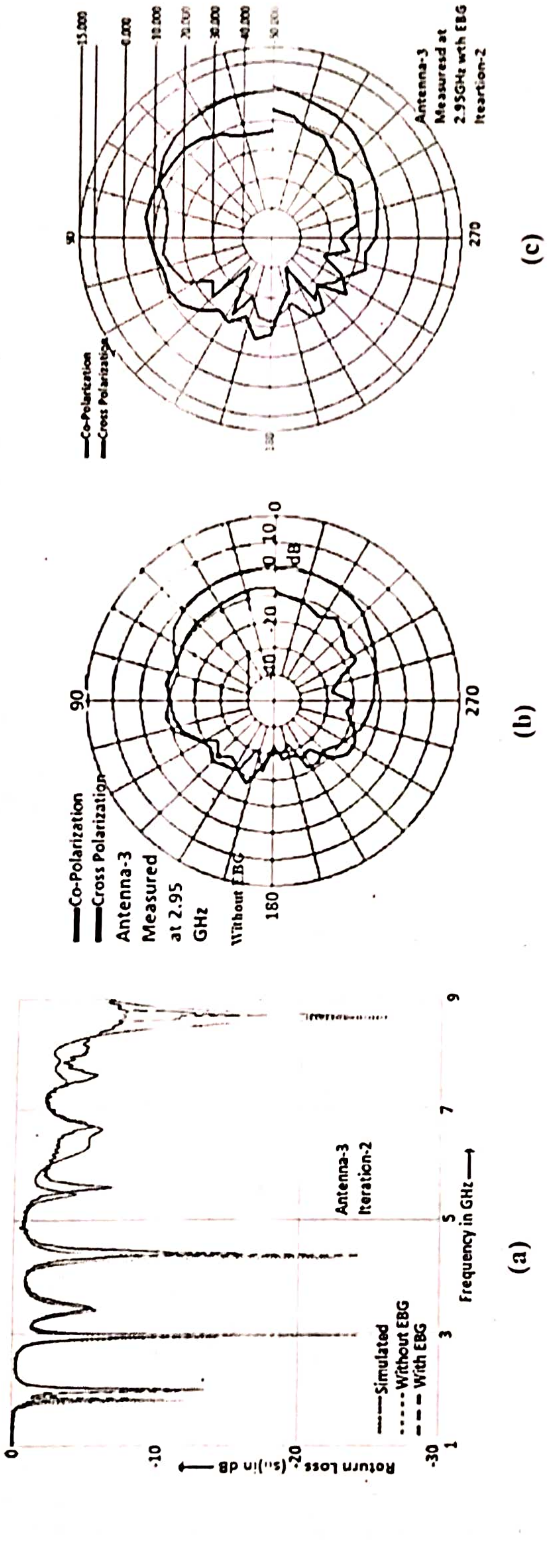


Figure 8.
Antenna geometry 3's input characteristics: (a) return loss vs frequency; (b) radiation pattern without EBG; (c) radiation pattern with EBG

Also, these resonant frequencies have useful for multiband frequency of operation along with larger BW and also for miniaturization of antenna size i.e. in S band uses such as bluetooth modules (2.4-2.48 GHz IEEE 802.11 b/g), long distance radio frequency communications, satellite communications and with these experimental results the reported antenna geometry is useful for WiMAX (2.5-2.69 GHz IEEE 802.16e and 3.4-3.36 GHz IEEE802.11a) and C frequency band applications.

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Corresponding author
Suresh Akkolecan be contacted at: sureshakkole@yahoo.co.in